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PREVENTION OF FIRES CAUSED BY ELECTRIC ARCS AND SPARKS FROM TROLLEY WIRES

BY

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PREVENTION OF FIRES CAUSED BY ELECTRIC ARCS AND SPARKS FROM TROLLEY WIRES[1]

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INTRODUCTION

Unquestionably mine fires now constitute one of the chief causes of sabotaging the effort to produce maximum quantities of mineral products essential to the prosecution of the war. This applies more particularly to coal than to noncoal mines, and presumably the main reason for this is the fact that coal production in maximum quantity is still very much a "must," while the demand for much of the product of noncoal mines has eased materially in recent months.

Since January 1, 1943, approximately 40 serious fires have occurred in the coal mines of the United States, and several times that number of additional lesser fires have been handled with minimum effort or loss of production or property. The loss of life from coal-mine fires in the United States during the 19 months, January 1, 1943 - July 31, 1944, has been far greater than in any other 19 months for more than 30 years.

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One hundred and four lives were lost in fires in coal mines in the past 19 months - 101 in fires caused by electricity and 3 in fires due to other causes. Four of the fires of electrical origin are chargeable to the trolley-haulage system, the deaths totaling 101. All of these fires of electrical origin occurred in highly mechanized mines. Three of the four fires of electrical origin with heavy loss of life occurred on a night shift.

In the past 19 months at least 12 coal mines were sealed at the surface because of fires, 3 having men in them; 16 men were sealed in a West Virginia mine, 6 in a bituminous mine in Pennsylvania, and 66 in a mine in Ohio. This record is one of which the coal-mining industry has little reason to be proud It is high time that coal-mining people became fire-conscious.

Inasmuch as bare trolley wires and the entire trolley-haulage system are outstanding sources of electric arcs and sparks, this publication proposes to suggest methods for minimizing and eliminating the hazards from this particular cause.

Approximately 50,000 miles of electrified underground haulage, chiefly the trolley type, are in service today in United States mines, representing an enormous capital investment. Every foot of bare trolley wire in a coal mine is potentially a fire originator, and nearly every foot is potentially capable of initiating an explosion. Obviously this equipment, which is efficient even though hazardous, cannot be discarded at once and replaced by other equipment; therefore, it is imperative that available equipment be carefully installed and maintained and safely operated if excessive loss of life and destruction of property are to be minimized.

Bare trolley wire can be eliminated from mines by substituting other mod of transportation, though up to the present no comparably efficient main-line haulage has been made available for underground mines. Improvements and alte ations in the present trolley-wire system can and should be made to minimize the hazards. Protective equipment for trolley circuits has not been develope to the point where positive tripping action is assured when arcs are formed through which low-intensity current is flowing, and there is urgent need for protective devices that will distinguish between fault current and useful current and deenergize the circuit when fault current is flowing through the circuit. A decided improvement over the conventional trolley-wire rail circuit is possible by replacing it with a fully insulated, two-wire, overhead trolley system though here again some definite hazards are likely to be encountered.

The ultimate solution of the basic problem is not immediately obvious and the cooperation of the industry is needed and constructive comments on the subject are invited.

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ELIMINATING BARE TROLLEY WIRE

Ultimately bare trolley wires should be eliminated from the mine-haulage system. Other modes of transportation are available to some extent now, namely, animals, mechanical conveyors, and locomotives powered either with a storage battery or with compressed air. Diesel locomotives suitable for use in coal mines may be available in the United States within a few years. Animal haulage and locomotives powered with compressed air are outmoded and will not be discussed, and the other possibilities listed are capable at present of being substituted for the trolley system only for certain limited uses.

Mechanical conveyors - belt, shaking, flight, and drag - are replacing mine cars as a transportation medium in face regions and in a few cases in an entire mine. The safety of these units compared with trolley-wire installation is obvious, although the fire-ignition hazard is not eliminated unless the power wires and conveyor control equipment are properly installed, adequately protected, and well-maintained. The practice of installing power wires haphazardly is far too widespread, and this should be remedied; in fact, it must be remedied if the bad fire-explosion record of electricity for the past several years is to be curbed. The safe way to install power wires is on insulators having enough dielectric strength to prevent leakage; the spacing of insulators is important, and it should be such that the power wires will not touch combustible material or other conductors. Suitable protection against overloading is highly desirable, and fuses and circuit breakers should be installed for this purpose and carefully maintained because, even if well-installed and carefully maintained, they still have definite weaknesses even though they give some protection. Maintenance of electrically operated equipment and appurtenances is important in fire prevention, thorough periodic inspections should be made by competent personnel, and complete detailed records of the inspections should be kept. Defects found during the inspection should be corrected immediately to prevent the development of serious trouble either soon or possibly some time later.

The economics of storage-battery locomotives and trolley locomotives is a much discussed subject and is beyond the scope of this publication. The comparison of the relative safety of the equipment favors storage-battery locomotives if designed, constructed, and maintained in conformity with Bureau of Mines permissibility requirements. The Bureau does not have a record of an explosion or a mine fire caused by permissible storage-battery locomotives that have been maintained in permissible condition.

The outstanding safety features of permissible storage-battery locomotives are:

(1) They can be operated anywhere in the mine.

(2) The self-contained power unit localizes the danger area.

(3) They are easy to inspect and repair.

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(4) Arcing is eliminated unless more than one ground (short circuit) occurs.

(5) Currents cannot stray from the locomotive.

The inherent dangers of a storage battery are:

(1) Hydrogen, an explosive gas, is liberated during charging.

(2) Overheating of a cell may result in a fire; if covered or partly covered by a fall of coal or rock, the storage battery may be broken and a fire started, very difficult to handle.

However, if proper precautions are taken during charging operations and the charging equipment is properly and safely installed much of the danger of f and explosions is eliminated.

Diesel locomotives have been used in driving some large-bore tunnels i the United States and are said to be in use in gassy and nongassy coal mine in European countries. German, French, and Belgian official stations have approved Diesel locomotives for use in gassy mines and relatively recently few Diesel locomotives have been placed in British coal mines. Although th Bureau of Mines has not approved Diesel locomotives for use in coal mines, approval schedule has been established, and it is expected that permissible Diesel locomotives will be available shortly after the end of the war.

One hundred and fifty-eight Diesel locomotives were in use in Belgian mines, as of July 1939. Single-cylinder, two-cylinder, and six-cylinder ty with horsepowers ranging from 9 to 85 were in service. The gas-ignition ha is eliminated by placing flame-arresting devices at the intake and exhaust ports; carbon monoxide gas is practically eliminated by complete combustion and by suitable ventilation; the other toxic constituents of the exhaust ga are rendered harmless by dilution with fresh air; and scrubbing largely de-odorizes the gases. The safe operation of Diesel locomotives underground w depend chiefly on maintaining the engine in effective mechanical condition all times; however, if the same disregard for maintenance of this equipment as is shown for electrical equipment in most mines, the Diesel equipment ca be used. Where used with care in tunneling, well-designed Diesel locomotiv have been both safe and efficient.

MINIMIZING HAZARDS FROM ARCS AND SPARKS

Mines now using trolley locomotives will not immediately discard this equipment in favor of any of the aforementioned substitutes, even the more efficient permissible Diesel locomotives if or when they are available; con sequently, the question arises, "What improvements can be made in the exist trolley-wire system to minimize fire and explosion hazards?" The following suggestions are enumerated and discussed to attempt to supply an answer to that question:

1. Space trolley-wire hangers properly.

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2. Have suitable insulation at each hanger.

3. Bond all track joints and crossbond at regular intervals.

4. Supplement the rail with a return conductor.

5. Maintain the conductivity and insulation of the circuit.

6. Install deenergizing switches at intervals of approximately 1,500 feet.

7. Install positive and sensitive automatic circuit breakers.

8. Provide effective protection against roof falls and derailments.

9. Sectionalize the trolley and feeder network.

10. Maintain and test circuit breakers regularly.

11. Remove power from circuits when not needed.

12. Make frequent inspections of the system.

Discussion of these suggestions:

1. Trolley and feeder wires should not touch the roof, timbers, or other combustible material at any time, inasmuch as such contact may cause current leakage that will result in a fire. If the supports for the wires are properly placed and spaced, freedom from contact with combustible material is readily feasible, and by keeping the wires taut, contact can be avoided even when the current collector is passing.

2. Numerous fires have occurred from overheating caused by leakage at the trolley hanger. Failure of a hanger insulator may be due to (1) failure of the insulator itself or (2) a conductive path established by deposits of dust or moisture on the insulator. Obviously, the hazards from this source of ignition can be minimized by installing additional insulators at each hanger. The dielectric strength of insulators should be tested periodically; and insulators falling below the manufacturer's specification of dielectric strength should be replaced.

3. The use of the track rails as one conductor of the system makes it decidedly important that the rails be electrically continuous. Each track joint, therefore, should be bonded, and each bond should be maintained in good condition at all times. Loose bonds will heat because of increased resistance. Overheated bonds and arcing at unbonded rail joints have caused numerous fires some of which were difficult to extinguish. Crossbonding is desirable for two reasons: The resistance of the rails as a conductor is reduced to a minimum, and some assurance of a continuous, low-resistance path for the current is gained. Crossbonds should be installed at approximately 200-foot intervals.

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4. The movement of haulage equipment introduces lateral stresses in the track which causes bonds to loosen and rails to break or to spread, and the resultant derailments cause damage to rail bonds, cross bonds, and the rails. A continuous copper conductor, equal in cross-sectional area to the trolley and feed wires, should supplement the track rails; this would provide a definite dependable return conductor. This supplemental conductor should be bonded to the track rails at approximately 200-foot intervals.

5. A continuous path for the current is necessary at all times from a viewpoint of safety, as well as that of maximum efficiency. Inefficient splices, corroded splices, loose bonds, and broken rails are points of high resistance and are very likely to heat abnormally when current is flowing. Overheating at these points will cause ignition of combustible material in contact with them. Furthermore, increased resistance increases the voltage drop in the circuit and low operating voltage induces heating in motor windings and trailing cables. Overheated trailing cables have been responsible for many disastrous fires and some explosions. The conductivity and insulati of the system should be checked periodically.

6. Deenergizing switches at about 1,500-foot intervals in the trolley-wire permit removal of current from a section of the wire in an emergency or for repairs and maintenance. The 1,500-foot interval places the switches at quickly available locations which should be plainly and conspicuously marked.

7. Circuit breakers may be defined as any devices for opening, deenergizing, or interrupting an electric circuit. They may be divided into two general classes, automatic and manually operated. The automatic types inclu release by a bimetallic strip or a spring mechanism actuated by an electromagnet. Fuses are also an automatic type of overcurrent protective device, differing from the circuit breaker in that the fuse is destroyed and must be replaced to restore the circuit. The manually operated circuit breakers are those types that require some manual effort in order to open or close the circuit.

For the purposes of this paper, a circuit breaker means a type having a magnetic spring-release mechanism that opens the circuit automatically.

The belief that circuit breakers offer protection against all short circuits is a fallacy. Protection is afforded only when the current flowing exceeds the trip-setting value of the breaker. The current flowing through an arc caused by a short circuit may be of such low intensity that the circuit breaker will not "trip," and unfortunately this happens far too frequently. The temperature of these arcs, whether from high- or low-intensity current, is sufficient to ignite any readily combustible material in the immediate vicinity, and the origin of numerous fires has been traced to this type of arc, particularly in the past few years. A type of circuit breaker that wil distinguish between fault current and useful current has not been developed; the need for such a circuit breaker, or some other device to deenergize the system automatically when a short circuit occurs (regardless of the intensit of the current), is paramount. Several ideas for such a device are given, which appear to be worthy of further investigation:

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(a) The application of the "high wave front" or rate of current rise in case of a fault as a means of actuating the trip mechanism.

(b) The development of a device that will actuate the circuit breaker by the sound waves or by high-frequency waves set up by an electric arc.

(c) The utilization of the rectifying properties of an arc to rectify an alternating current superimposed on the trolley circuit to operate the trip mechanism.

8. Falling roof material and derailed haulage equipment often damage the trolley wire and in some cases cause a direct short-circuit path from the wire to the rails. To reduce this hazard, the roof in haulageways should be inspected far more frequently and more effectively than is ordinarily done at present. Loose and dangerous roof should be removed or else securely supported, and all feasible precautions should be taken to protect the trolley wires when scaling the roof or timbering around or above the trolley wire. The wires should be deenergized, and if large slabs are likely to be pried down it is well to set a row of breaker posts near the trolley wire. At no time should the roof be scaled while the trolley line is energized. The hazards from derailed haulage equipment can be minimized by effectively maintaining the haulage tracks and rolling equipment and by placing timber in such manner as to make it difficult for timber to be torn out because of derailments. Rails should be of adequate size; the ties should be sufficient in number for adequate support and properly ballasted to maintain alinement and grade; and timbers along trolley haulage should preferably have posts recessed into the rib to prevent their being torn out by derailed cars.

9. By sectionalizing the trolley and feeder network into a series of branch circuits and protecting each with a circuit breaker, many advantages are gained; this at least should be done. The principal safety advantage of sectionalizing is that branch circuit breakers can be set to function when a current slightly in excess of the normal load is drawn in that circuit; thus, a relatively low-resistance short circuit will be interrupted and fires probably prevented.

10. The electric contactors and mechanical moving parts of circuit breakers are susceptible to failure because of corrosion caused by oxygen and moisture from normal air and dust. Enclosing these parts to exclude air, dust, and moisture is not always feasible; therefore, it is desirable that periodic inspections be made to insure proper operation. The inspection, testing, and cleaning should be done by a person familiar with the construction, operation, and limitations of circuit breakers. Tampering with the setting or adjustment of circuit breakers to interfere with or prevent proper operation should be severely handled; this is by no means an unusual procedure in coal mines, and the hazard from it is not recognized to anything like the extent that it should.

11. Each circuit should be deenergized during the off-shift period; this practice should be mandatory at every mine, yet it is found in relatively few

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mines. Numerous fires have resulted from energized circuits during idle periods and they have burned undetected for several hours, often making it nearly impossible to handle them adequately. Where it is necessary to operate gathering pumps or other comparatively light-load equipment during the off-shift period, a low-current fuse can be connected in shunt with the circuit switch, or a special low-current magnetic coil can be installed and set to actuate the circuit breaker. The protection thus afforded will greatly minimize the danger of an electrical fire during idle periods.

12. The underground electrical system, as a whole, should be carefully examined and inspected periodically by a competent person. These inspections should disclose faults, unfavorable conditions, and defects before serious damage occurs. This procedure, if done carefully, should do much to assure continuity of mine operation as well as to improve the over-all safety of the electric installation.

TWO-CONDUCTOR OVERHEAD TROLLEY SYSTEM

A two-conductor overhead trolley system that is insulated from both track and strata appears to offer a possible answer to several hazard problems connected with the conventional trolley system. The apparent advantages of the two-polarity or dual trolley-wire system are:

1. A ground detector can be used in connection with a circuit breaker to interrupt the circuit.

2. Sustained arcing of dangerous proportions can be eliminated.

3. Stray electric currents, hazardous to electric blasting, can be eliminated.

4. Electric shock hazards can be lessened.

5. The hazard of arcs burning through locomotive controller compartments can be virtually eliminated.

6. Track bonding can be eliminated.

7. The hazard of fires originating from current leakage can be greatly reduced.

8. Present trolley locomotives can be wired for two-conductor system.

9. Greater efficiency can be realized because of better voltage conditions.

DISCUSSION OF ADVANTAGES

1. With the conventional grounded trolley system, fault currents of considerable proportions can flow without tripping the ordinary circuit breaker, since both the useful and fault currents flow to or from the ground. On the

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other hand, a fully insulated system (dual trolley) offers possibilities of using ground detectors or equivalent that can be applied to circuit breakers so that any predetermined value of current in ground or track can be made to trip the circuit breaker. Thus, sustained arcing could be eliminated.

2. Owing to the low resistance and continuity of the dual trolley wires, overload circuit breakers of the ordinary type, as well as improved types, will provide greater protection against fault current between conductors.

3. With the fully insulated dual trolley system, together with sensitive ground detectors, stray currents in strata or track having sufficient magnitude to fire electric detonators, squibs, or blasting devices can be eliminated; the present trolley system is responsible for much of the trouble from stray currents found in some mines. Moreover, the elimination of stray migrating direct currents through pipe lines and buried armored cables will prevent their deterioration by electrolysis; this would result in a considerable saving in many mines where electrolysis is a serious problem.

4. With the insulated system and ground-detector-actuated circuit breaker, no dangerous voltage differences should exist between strata, track, locomotive frame, or the metal frame on mine cars. With this system, it would be necessary to touch both conductors simultaneously to receive a serious or fatal shock; however, this could be done, and it constitutes one of the worst hazards from the proposed system especially in low coal.

5. With the conventional single-trolley-wire system, the locomotive frame is connected metallically to the track conductor. Any arcs established in the controller tend to short-circuit to the metal enclosure. When such an arc contact is made with the enclosure, it often persists until the metal is fused and the arc flame extends to the exterior. This fusing of metal and extension of the arc flame have, in many cases, severely burned the locomotive operator. A similar hazard exists with other electrical compartments when one of the conductors of the transmission system is connected intimately with earth. With the dual trolley, this hazard can be practically eliminated.

6. The two-wire overhead system obviates the need of the track rails as a conductor. Track bonds and the ignition hazards of defective bonds and defective rails are eliminated. Circuit maintenance is confined to wires and insulators, and to the control and protective devices.

7. Many mine fires have originated at trolley-wire hanger supports, where the supports were fastened to a coal and rock laminated roof structure or to wooden beams. The ignition was caused by electric current leaking through or over the insulating spool, owing to failure of the insulating compound or to depositions of coal and rock dust, which may become conductive when admixed with moisture. Many fires also have been caused by current leakage between a fallen trolley wire and a rail.

With the insulated dual wire system, the potential difference of the circuit is between the two-wire conductors rather than through strata to rail, as would be the case with a single trolley-wire rail circuit. Two insulated hangers are connected in series with the two-conductor overhead system. This

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provides at least twice the insulating medium between conductors that is ordinarily found with single wire overhead. To further mitigate leakage to strata with the two-wire system, a third insulator should be interposed between the roof and wire supports. With the dual system there should be little if any current leakage between a fallen wire and a rail.

8. The main change necessary in the electric wiring of existing trolley locomotives would be to disconnect the motor lead from the frame and connect it to a second trolley collector.

9. Better motor-terminal voltage should obtain with the dual trolley system, and a short-circuited conductor in the motor, resistor, or controller enclosure would not be as destructive as with the trolley-rail system. Thus, maintenance and replacement of parts would be reduced.

CONCLUSIONS

The fire hazards from bare trolley-and feeder-wire systems in coal mines must be minimized or eliminated if many disastrous mine fires are to be averte fires of this type are increasing both in number and in severity, as regards both loss of life and property. Electricity in mines should be regarded with at least as much respect as electricity on the surface; in fact, there are numerous reasons why even greater care should be exercised in the installation and maintenance of electric equipment in underground mines than in surface installations, for in no other industry are fire and ignition sources so potentially hazardous to life and property.

The inherent fire hazards of the conventional single-wire trolley system can be mitigated by the suggested improvements discussed and can be minimized by the use of a two-wire overhead trolley system, even though that system has hazards of its own.

The usual type of circuit breaker does not provide adequate protection against sustained electric arcing in the conventional trolley-wire system. Th development of protective devices that will distinguish between fault current and useful current is therefore highly desirable.

The use of bare trolley wires in coal mines should be eliminated as soon as this is feasible; the use of locomotives powered by storage batteries can and should displace the trolley system for much if not most gathering purposes and there is a possibility that suitably designed Diesel locomotives will be available after the war capable of displacing many if not most of the trolley locomotives now in use for main line haulage.

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